WASTE HEAT RECOVERY THROUGH COGENERATION IN SELECTED INDUSTRIES IN INDIA

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1.0 Introduction

In this era of energy conservation, particularly in the industrial sector, cogeneration - defined as combined generation of electricity and heat has started receiving wider attention.

Combined generation of electricity and heat can be effected in either of two ways, viz. "topping" system where generation of electricity comes first, or "bottoming" system where electricity comes last (Barnes,1980; Marcel Dekker, 1980) bottoming system. The primarily a waste heat recovery mechanism', with a waste heat boiler, a turbine condenser and feed pump, operates under conventional or modified Rankine cycle. The candidate industries for bottoming system of cogeneration could be those which release their waste streams (usually gaseous products of combustion) to the atmosphere from as high as 650° Centigrade (e.g. exhaust from gas turbines), medium temperature range in excess of 315° Centigrade and to a lower temperature range between 120 and 370° Centigrade.

The aim of the present study is to prepare a comprehensive paper on bottoming system cogeneration as related to energy use and industrialisation, with particular reference to the Indian scene.

2.0 Literature Survey

Several researchers, Barnes R.W., (1980), Gunn, Jr. (1980), Dryden I.G.C. (Ed) (1975), Chigioji M.H. (1979), Reay, D.A. (1979), Seplow, K.F. (1982) and Gyftopolus E.P. and T.F. Widmer in developed countries have worked on the theory and practice of cogeneration - both in topping and bottoming cycles, under different names viz., total energy system, combined cycle, cogeneration, energy cascading etc. The majority of work, however, has dealt with technical and economic aspects of cogeneration. One of the papers (See;pw,1982) has discussed the fiscal and legal sides of cogeneratio in the U.S. It is interesting to note that between the two systems of cogeneration, the topping system gets prominence as a candidate with greater potential. The bottoming system has been considered 'primarily a waste heat recovery mechanism. As such it competes with recuperators, feed water heaters, process heat exchangers, and other heat recovery systems'(Barnes,1980). This viewpoint may not be totally correct, as we shall see later, when use of waste heat is restricted to generation of electricity alone.

In India, the picture of the extent of development of bottoming system cogeneration, in terms of technology development or acceptance by industry is not very clear. The main reason for this situation is lack of published information, both by organisations who have been assessing the potential of cogeneration, technology etc., by industry itself and at the organisation level, the National Productivity Council (NPC), singly, or jointly with the Petroleum Conservation Research Association (PCRA), has conducted several field studies on waste heat recovery in general(Padmanabhan,1983). NPC's own studies have mostly been of the consultancy type, suiting the requirements of client units covering a wide range of industries like rubber, cement, mini-steel plants, jute, textiles, inorganic chemicals, non-ferrous metals, glass, ceramics, etc. The thrust of such consultancy studies has been to suggest to respective client units the short and long term measures of energy conservation, viz., stopping leaks, better insulation, and supply of techno-economic information on a waste heat recovery system that would suit a particular unit. NPC has so far done 200 such studies, which are based on an one time energy audit of a unit. By their very nature the findings of such studies are confidential.

In a bid to suggest to the Government of India, the ways and means to reduce the demand for petroleum products through energy conservation at unit level of industry, NPC and PCRA conducted a survey of 1200 industrial units, usually intermediate and small scale industry, which consume a specified minimum amount of petroleum based fuels. The large scale units like integrated iron and steel plants, petroleum refinery, aluminium plants, are usually excluded from such surveys because such units are assumed to be conscious of energy conservation and to have taken steps in the right direction. For each of the 1200 units mentioned above, an individual report has been prepared covering, among other things, potential of waste heat recovery. PCRA also has prepared a white paper based on findings of all these individual reports, which has not yet been published.

Based on such background, NPC has conducted three seminars(9-11) on waste heat recovery in the recent past. Other organisations participated in such seminars and was laid on the technology of waste heat recovery, policy recommendations, and making industry aware of possible benefits from energy conservation through waste heat recovery.

A culmination of all such activities of the NPC, perhaps, took the form of a report of an inter-ministerial working group which outlined the possible strategies and policies for energy conservation in industry(Interministerial Working Group Report on

Strategies and Policies for Industrial Energy Conservation,1983). Two chapters in Part 1 of the Sub-committee Report volume were devoted to industrial cogeneration and waste heat management. The chapter on industrial cogeneration deals with such topics as thermodynamic theory of total energy. Its examples apply to different types of industry, broad findings of NPC on topping system cogeneration, total energy technologies which are universally available, different barriers to implementation of total energy systems and finally the recommendations. The next chapter of the report dealing with waste heat management covered topics on standard techniques of electricity generation, different types of waste heat recovery systems that are usually available, benefits and costs of such equipment, general constraints in waste heat recovery and their solutions, and recent developments in waste heat recovery that are usually available in industrially developed countries. Here again, at the end of the chapter a series of recommendations have been included.

The treatment of cogeneration and waste heat recover the reports is general. It is noteworthy that in t two chapters, and elsewhere in Part I of the - Committee's Report, no detailed analysis of data from field survey on 200 and 1200 units that have been energy audited by the NPC and PCRA respectively has been given. There have been, of course, certain cursory conclusions of NPC's study findings of 28 manufacturing units and status of operating boilers and captive power plants in the country. However, the Sectoral Reports (energy Audit Studies) covered 12 categories of industries. These audit reports generally dealt with such topics as technology of manufacturing, energy consumption patterns as obtained from sample units surveyed, energy conservation opportunities and estimates of fuel savings through suggested energy conservation opportunities. The findings in these reports were more specific. However, one might question the bases for selection of industries, sample size and representative nature of sample chosen in each category of industry. Except for the cement industry - which, according to the audit report, was capable of generating 1MW of electrical power from exhaust gas of a 1000-tonnes-per-day plant - no other industry was found suitable for bottoming cycle cogeneration. The audit reports did not provide any information about quantity of waste gas produced by sample units surveyed in cement, steel rolling and forging, glass, and refractory industries, so that one could judge the feasibility of bottoming cycle cogeneration for these categories of industry.

The potential of bottoming cycle cogeneration in ferroalloys industry has been discussed in one of the seminars on "Captive power generation" held at Calcutta in

1979(Ghorpade,1979). The paper points out prospects of cogeneration in a typical ferrosilicon unit.

In summary proceedings and papers of a workshop(Industrial Credit and Investment Corporation of India Ltd.,1982) on energy for selected industries such as caustic soda, soda ash, aluminium, ferroalloy and electric are furnace steel, several authors have discussed energy conservation potential that exists for these industries. Much attention was paid to reduction in electrical energy consumption by technology updating, and it was also recognised that in industries such as ferroalloys and electric arc furnace steel there was scope for energy recovery, and even cogeneration for the former. However, none of these papers contained any in depth discussion on cogeneration that might be fruitful in Indian conditions.

The proceedings of the BHEL seminars on waste heat recovery system(Bharat Heavy Electricals Ltd.,1983) contained seven papers. Of these, four papers had been presented by BHEL representatives and others by those from NPC, Bokaro Steel and Development Consultants (P) Ltd., Calcutta. The BHEL papers dealt with design and performance of waste heat recovery system components, application of such system in the cement industry and the potential for power generation from cement plants of different capacities. The papers from Bokaro Steel were general and showed thermal energy consumption and waste heat generation patterns in different units in an integrated steel plant. Likewise, other papers were general in nature and there had been no attempt, in any of the papers presented, to study the techno-economic feasibility and different impediments to retrofitting cogeneration facilities to a few representative units of cement, integrated iron and steel or any other industry rejecting heat at medium temperature range.

These are the few reports, studies etc. which are available to researchers working in the field of energy conservation. Whatever work has been done in this area is isolated and has been carried out according to the working orientation of a particular organisation or institution. For example, NPC offers consultancy services to industry and BHEL would like to promote its market for the waste heat recovery facilities it manufactures. Published work has been aimed at creating awareness for waste heat recovery, but, there has been no systematic study of a representative sample of the Indian manufacturing industry sector covering energy utilisation and waste heat generation patterns, that could be a precursor to the present study.

3.0 Scope and Methodology Of The Present Study

The present study would primarily concern itself with potential of bottoming system cogeneration in some candidate high temperature (of the main process) industries and assessing as to what extent this mode of cogeneration has influenced, or is likely to influence energy patterns in these selected industries. It should be mentioned here that the list of candidate industries is limited by the scope of the study because, as mentioned earlier, bottoming cycle cogeneration competes with other methods of waste heat recovery. Thus, the bottoming cycle cogeneration can be employed in a unit, if

- Quantity (or flow rate) of waste heat carrying stream is adequate;
- Quality (i.e. temperature and combustible contents of streams) of waste heat is sufficiently high;
- Temperature requirements of the working fluid cycle ;
- The industry concerned has a major use of electrical energy .

It is, therefore, seen that the above mentioned four conditions limit, somewhat, the types of industries that we would be able to cover. The industries* that would possibly cover the four conditions are :

- Integrated iron and steel
- Ferroalloys
- Glass

The TERI research team conducted a macro (comprising all or majority of units) survey for the first two types of industries, and a micro (covering only one unit) survey of the glass industry, as regards energy consumption and production patterns of these three industries.

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*The reason for not choosing an energy intensive industry like cement is that more and more cement units are employing dry process technique with suspended preheaters, where waste heat from kiln is used to preheat the incoming charge. This eliminates the possibility of installing bottoming cycle cogeneration system, otherwise a competitor of suspended preheater system,in case of cement.

The data base of the integrated iron and steel industry had been the early published statistics of each integrated iron and steel plant(Steel Authority of India Ltd.,1979). Out of six units, functioning of four units in the public sector were chosen for the present study, because past annual statistics of these units were conveniently available. Processing of such data would be adequate to estimate energy consumption patterns with componentwise breakup, average energy intensities of all intermediate and final products for the period between 1970 through 1979. The impact of bottoming system cogeneration, particularly on processes such as coking and oxygen steel making can be assessed at this stage.

For the ferroalloys industry (that includes other industries employing submerged electric smelting furnaces), typical information on energy consumption, production of ferroalloys and capital investment for future cogeneration projects were sought for analysis. The objectives were similar to those of integrated iron and steel industry and also involved the estimation of a profitability index for installing cogeneration facility.

The glass industry in India is a large consumer of petrofuel. A single unit near Delhi was chosen for a detailed energy audit of the plant that include working out heat balances of furnaces, energy analysis of the entire plant, estimating impacts of price changes on major inputs of energy intensity and cost of production of glass. The scope of the study also included an examination of techno-economic viability of a scheme of bottoming cycle cogeneration from waste gas from furnaces. Here again, the impact of cogeneration on energy consumption by glass industry would be discussed. Thus, the potential energy savings that bottoming system cogeneration can cause in the three specified industries, would be the key point of the entire study.

A review of each of the three industries along with discussions on TERI's findings now follows:

4.0 Integrated Iron and Steel Industry

4.1 Present Status and Future

There are at present six integrated iron and steel units, with a total annual production capacity of 10.6 million tonne of ingot steel. With the commissioning of the Vishakapatnam plant, expansion of Bhilai and Bokaro units and modernisation of TISCO, the estimated production capacity of all the units by the year 2000 would be 18.3 million tonnes.

4.2 Energy Consumption Pattern

Modern iron and steel plants are designed to operate with both primary and derived sources of energy. The examples of primary sources are coking and non-coking coals, purchased electricity, diesel oil, furnace oil, etc. The derived forms of energy are those derived from primary forms and include such fuels as coke oven gas, blast furnace gas and electricity produced in the captive power plants. The average percentage contribution during the last decade by each of the primary fuel sources have been estimated for each of the four public sector steel plants from respective operational statistics and are given in Table 1.

Table 1: Average Contribution of Primary Energy Resources to Public Sector Steel Plants during Seventies

Primary Sources of energy	Steel Plants and Periods				Assumed Thermal Equivalence
	Bhilai (1970-71 thro' 1978-79)	Bokaro (1976-77 thro' 1979-80)	Durgapur (1970-71 thro' 1978-79)	Rourkela (1970-71 thro' 1978-79)	
Coking coal	82.05	76.99	78.19	77.71	6.4 G.cal/tonne
Non-coking coal	8.35	12.62	8.68	10.01	5.8 G.cal/tonne
Purchased Electricity	9.29	10.17	8.82	12.08	4.28 G.cal/MWH of 20% thermal efficiency of thermal power plants.
Diesel Oil	0.31	0.22	0.18	0.20	10 G.cal/tonne
Furnace Oil	-	-	5.13	-	-do-

Note: Estimated by the author from the data (Steel Authority of India Ltd.,1979).

From the figures in Table 1 above, one could surmise that:

- By far the largest contributor to the energy supply to steel plants is coking coal, varying between 77 per cent for Bokaro and 82 per cent for Bhilai.

- On the other hand, contribution of diesel oil, which is mostly used for running locos, is the least, i.e. less than 1%.

The respective contribution of non-coking coal and purchased electricity are similar and are within a range of about 13 and 8 per cent.

4.3 Energy Intensities of Intermediate and Final Products:

Operation of an integrated iron and steel plant is mostly centered around coke ovens, sintering plant, blast furnace, steel melting shop and rolling mills. The primary raw materials are coking coal and iron ore; fluxing agents like limestone are also needed. In coke ovens, coking coal is carbonised to coke. Iron ore fines are sintered in sintering plant and coke, lump iron ores, sintered ores and limestone are charged to blast furnaces, where iron ore gets metalised to pig iron. The pig iron in molten condition is charged into furnaces (converters or open hearth furnaces) in steel melting shop along with steel scraps, fluxing agents etc. for conversion to steel. The steel from steel melting shop is sent to rolling mills for shaping to final desired forms.

Thus, we see that in an integrated iron and steel plant outputs from coke ovens and sintering plant become input to blast furnace. Output of blast furnace, i.e. molten pig iron becomes input to steel melting shop. This process continues till the final rolled products come out. Energy inputs are needed in each transformation stage and a shopwise energy analysis would reveal the extent of energy needed to produce a tonne of output. This specific energy consumption, known otherwise as energy intensity or net energy content has been estimated by energy analysis(IFIAS Workshop Report on Energy Analysis and Economics,1978) of manufacturing process adopted in each shop of the four public sector steel plants during the period from 1970 through 1979. The required data were obtained from past operational statistics(Steel Authority of India Ltd.,1979). The average net energy contents of four products for all the four plants are given in Table 2.

Table 2: Average Energy Contents of Principal Energy Embodied Materials of Four Iron and Steel Plants during Seventies

(in G.cal/tonne of material)

Steel Plant	Materials				Remarks
	Coke	Sinter	Pig Iron	Steel	
Bhilai	8.03	1.15	6.58	8.31	Entire steel production by open hearth furnaces.
Bokaro	7.39	1.20	6.40	7.81	Entire steel production by converters.
Durgapur	8.23	1.23	7.82	10.89	Entire steel production by open hearth furnaces.
Rourkela	9.00	1.37	8.18	i)11.17 (conv) ii)19.11 (OH)	About 80% of steel production by converters and the rest by OH furnaces.

Note: Evaluated by the author from the data in (Steel Authority of India Ltd.,1979).

It can be seen from energy intensity figures in Table 2 that:

- Energy intensity of coke from all the four plants vary within a small range.

- Inter steel plant variations in energy intensity figures for sinter and pig iron are small.

- The low energy intensity figures of steel produced by converters (e.g.Bokaro) compared to that produced in open hearth furnaces (e.g. Bhilai) indicate that converter process is more energy efficient.

4.4 Bottoming Cycle Cogeneration Opportunities in an Integrated Iron and Steel Plant

There are two(Battele Columbus Laboratories,1975) distinct areas where this type of cogeneration can be employed. These are

- Dry quenching of coke

Utilisation of offgas from basic oxygen furnaces

4.4.1 Dry Quenching of Coke (Chiogioji, 1979)

In this process hot run-of-oven coke is quenched by a cold inert gas, instead of quenching by water as is done conventionally. The soviet Union has modernised the concept and dry quenching is compulsory for new coking plants.

In dry quenching of coke, there is direct heat transfer between hot incandescent coke and cold inert gas. During the process, coke cools down from about 1100° Centigrade to about 230° Centigrade and temperature of the gas rises to about 775° Centigrade. This high temperature gas, after passing through dust dropout chamber enters into a waste heat boiler to raise a high pressure steam, the quantity of which is nearly 475 Kg.per tonne of coke quenched. The steam produced is a superheated one at a temperature around 440 deg.C and at 34 atm.pressure. With an assumed steam enthalpy of about 700 K/cal per Kg. steam, the amount of energy that could be conserved works out to be about 333,000 K/cal per tonne of coke quenched.

4.4.2 Utilisation of Offgas from Basic Oxygen Furnaces(Chiogioji,1979;Battele Columbus Laboratories, 1975; Fortnightly Journal of Industry and Commerce (Oil and Coal News, 1980)

During blowing of oxygen through basic oxygen converters, large volume of furnace offgas is generated. The generated gas is rich in carbon monoxide (about 90%) and the quantity produced is of the order of 70nM3 per tonne of steel produced. This gas has both sensible heat (from being at a high temperature of about 1000° Centigrade) and latent heat of the order of 2,250 K.cal per nM3 . The total energy associated with BOF offgas has been estimated to be around 41,670 K.cal per tonne of steel produced.

4.5 Potential of Energy Conservation

In India, there is a distinct possibility of installing coke dry quenching facilities as well as utilisation of BOF offgas for generation of steam and subsequently electrical energy through steam turbine and alternator system, in one or more steel plants. For example, coke dry quenching facilities of Soviet design would be set up in the Vishakapatnam Steel Plant(The Hindu Survey of

Indian Industry, 1982) and subsequently in the Bhilai and Bokaro steel plants. Bokaro has already negotiated with M/s Head Wrightson Process Engineering Ltd., U.K. for the design, supply and erection of a plant employing IRSID-CAFL (of France) process for recovery of converter offgas. It is expected that other steel converters, particularly those at Rourkela, Bhilai and also the units being erected at Vishakapatnam would be equipped with similar facilities.

From the discussion above, one can estimate the extent of energy saving in the the Indian iron and steel industry, that is viable at the turn of this century, by employing bottoming-cycle cogeneration in the two production shops, viz., coke ovens and steel melting. This can be attempted as follows.

In the first step, we estimate the amount of energy that would be required upto steel melting to produce 18.3 million tonnes of steel, with the present status of technology. This can be obtained by multiplying the raw steel production capacity of each plant with respective average energy requirement of raw steel (Table 2) and adding the total amount. For IISCO, TISCO and Vishakapatnam plants, we may assume Durgapur, Rourkela and Bokaro figures respectively.

We assume, in the second step, that by the year 2000, Vishakapatnam, Bhilai and Bokaro plants would be equipped with coke dry quenching facilities and all the converters in Bokaro, Bhilai, Rourkela, TISCO and Vishagapatnam would be equipped to recover furnace offgas, and the resultant net energy requirements of coke and raw steel are then estimated. These are summarised in Table 3.

It can be seen from figures in Table 3 that, if the projected cogeneration facilities are incorporated as mentioned before, the total energy consumption (upto steel melting units) for all the integrated steel plants would be reduced from 174.21 x 10^{15} to 169.83 x 10 calories per year, or a reduction of 2.5 % at the turn of century. The thermal energy thus saved is equivalent to 146 MW of electric power, if cogeneration is employed.

Though the relative saving due to cogeneration does not appear to be high, the project might be financially attractive because, majority of the steel plants have already captive turbo-generator sets and capital

Table 3: Energy Conservation Potential in Indian Iron and steel Industry by Bottoming Cycle Cogeneration

Plant	Annual Raw Steel production capacity (10 tonne) in year 2000	Specific net energy consumption upto steel melting stage, with present technologies (G.cal/ tonne of steel)	Total Energy consumption upto steel melting stage with present technology (G.calx 10)	Specific net energy consumption upto steel melting stage with cogeneration facilities incorporated (G cal/ tonne of steel)	Total energy consumption upto steel melting stage with cogeneration facilities incorporated (G.cal x 10)	Remarks
1	2	3	4	5	6	7
Bhilai	4.0	8.31	33.24	7.94	31 76	In order to arrive at figures for specific energy consumption with cogeneration facilities use was made of average specific material consumption figures of each of the steel plants and the cogeneration facilities project for each plant.
Bokaro	4.0	7.81	31.24	7.44	29 76	
IISCO	1.0	10.89	10.89	10.89	10.89	
Rourkela	1.8	12.76	22.97	12.72	22.90	
TISCO	2.5	12.76	31.90	12.72	31.80	
VSL	3.4	7.81	26.55	7.44	25.30	
			174.21		169 83	

Note Evaluated by the author.

investment would be minimal.

A strong contender for BOF offgas recovery for cogeneration would be use of offgas as balancing fuel for the steel plant. The choice of course would depend on the availability and price relative of purchased electricity and fuel.

In addition to waste heat recovery potentials mentioned above, waste heat recovery in the form of steam is practised in the open hearth furnaces of Bhilai and Durgapur. These furnaces are fitted with waste heat boilers after regenerators, Bhilai open hearth furnaces are equipped with evaporative cooling systems which augments waste heat recovery. However, with gradual phasing out of open hearth furnaces from Indian steel industry, the significance of waste heat recovery in open hearth furnaces would decline. But the evaporative cooling system can be very effectively incorporated in the hoods of basic oxygen furnaces, thus serving the dual purpose of hood cooling and steam generation.

5.0 Ferroalloys Making Industry

5.1 Present Status and Future

Ferroalloys are alloys of iron and other elements such as manganese, silicon, chromium, etc., and ferroalloys made through electrothermic process requires substantial amount of energy in the form of electricity and reductants like coke. Ferroalloys are inputs to steel making industry which impart alloying elements and thereby, certain desirable properties to finished steel. For manufacture of tonnage, ferroalloys like, ferromananese, ferrosilicon, ferrochrome, etc., electro thermic process, making use of submerged arc furnaces, is employed. Depending upon the type of ferroalloys being produced, open or closed top furnaces are used and incoming raw materials are preheated and prereduced.

According to the technology prevalent in India, the co-product of ferroalloys is furnace offgas, which is made mostly of carbon monoxide - a gas having considerably high calorific value*. This furnace offgas is, at present, burnt at the furnace top thereby wasting a large quantity of energy.

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*Submerged electric furnaces are in use to produce items like calcium carbide, silicon carbide and even pig iron. Here again, carbon monoxide constitutes the large part of furnace offgas. In India, such gas is already put to use e.g., calcining limestone in calcium carbide units. This is again a case of cogeneration competing with other methods of waste heat utilisation.

There are, at present, 12 units manufacturing tonnage ferroalloys and alloy intermediates like silicon chrome etc. None of these units are equipped with waste heat recovery system. The total installed capacity of all the 12 units is 3,54,700 tonnes per year. Out of these, the installed capacity for ferromanganese is 2,18,300 tonnes per year, followed by 79,000 tonnes per year of ferrosilicon and 20,000 tonnes per year of ferrochrome.

The future requirement of each of the three major ferroalloys has been estimated by econometric analysis of the past time series data on consumption of each of the ferroalloys as dependent variables, and production of raw mild steel and special steels, and net national income as explanatory variables. The total requirement of tonnage ferroalloys worked out to be 5,67,081 tonnes for the year 2000, on the assumption that NNP would grow at a rate of 5% per year and requirement of raw mild steel would be around 24 million tonnes in the same year. Of the total requirement of ferroalloys, the shares of ferromanganese would be 4,06,607 tonnes, ferrosilicon and ferrochrome 1,14,766 tonnes and 45,708 tonnes respectively.

5.2 Energy Consumption and Energy Conservation Potential

The high volume of energy needed to manufacture tonnage ferroalloys is in the form of coal (or coke) and electricity. The raw materials like metalic oxide ores and coal or coke are melted together in an electric furnace. Most of the heat is supplied by electricity, which is considered a 'raw material'. For a typical 30 MW furnace, 10,000 Kwh of energy comes from reductants and another 9,000 Kwh from electricity for each tonne of ferroalloy produced(Eriksen, 1979).

Analysis of energy consumption and ferroalloys production figures, based on one year data of nine ferro- alloy making units, show that energy intensities of different ferroalloys vary within a broad range. As mentioned before, energy is supplied in the form of electricity, reductants and also in non-fuel forms like steel scrap and intermediates like silichrome, silicomanganese etc. The average composition of energy intensity of tonnage ferroalloys manufactured in India in a recent year is given in Table 4.

Table 4:Consumption of Average Energy Intensities of Some Ferroalloys Manufactured in India

Contribution to energy intensity through	Types of Ferroalloys and Intermediates						
	Ferro manganese (High carbon)	Ferro manganese (Sup. Grade)	Ferro-silicon	Ferro chrome (High carbon)	Ferro chrome (Low carbon)	Silico-manganese	Silico-chrome
1. Electricity[(a)]							
a) G-cal/tonne	13.38	9.82	38.06	19.59	22.41	20.99	33.64
b) %age	67.50	20.62	65.23	73.63	32.02	76.00	74.50
2. Reductants							
a) G-cal/tonne	6.27	-	18.33	6.61	-	6.35	7.45
b) %age	31.60	-	31.42	24.83	-	22.99	16.51
3. Steel Scrap and intermediates							
a) G-cal/tonne	-	37.48	1.32	0.06	43.79	-	-
b) %age	-	78.68	2.25	0.22	62.58	-	-
4. Others							
a) G-cal/tonne	0.18	0.34	0.64	0.35	3.78	0.28	4.06
b) %age	0.90	0.70	1.10	1.32	5.40	1.02	8.99
5. Total							
a) G-cal/tonne	19.83	47.64	58.35	26.60	69.97	27.62	45.16
b) %age	100.00	100.00	100.00	100.00	100.00	100.00	100.00

(a) The thermal equivalent of 1 Mw-hr of electrical energy is assumed to be 4.28 G-cal of thermal energy.

Note: Evaluated by the author from data sent by ferroalloys manufacturers.

The following broad coclusions can be drawn from figures in Table 4:

- The direct electrical energy requirements for high carbon ferromanganese, ferrosilicon, high carbon ferrochrome, silicomanganese and silico-chrome vary between 65 and 76 % of the total energy intensity.

- The shares of reductants alone for these ferroalloys vary between 17 and 32 %.

- The shares of direct eletrical energy for superior grade ferromanganese and low carbon ferrochrome vary between 21 and 32 % of total energy intensities.

Energy conservation can be done by recovering and utilising the sensible and latent heats of furnace offgas. This offgas is rich in carbon monoxide, the other constitutent being methane. The dust content of gas varies between 20 and 200 gms per nM3 of gas (Dave and Sitaram,1977). Depending upon the ferroalloy being produced, the yield of gas varies per tonne of ferroalloy produced. For example, the gas yield is 1720 nM3 per tonne of ferro- silicon(Industrial Credit and Investment Corporation of India Ltd., April 17, 1982) and 600 to 800 nM3 per tonne of ferro- manganese(Bombay Stock Exchange).

A scheme known as DSLA Recovery System has been developed(Industrial Credit and Investment Corporation of India Ltd., April 17, 1982; Dave and Sitaram, 1977) for recovery of energy from ferro- silicon furnace offgas, on the concept of bottoming cycle cogeneration. In this scheme, an open furnace is semi-closed, causing thereby an increase in offgas temperature to about 800 deg.C from the usual 175-300 deg.C, a reduction in ingress of atmospheric air and a reduction in flow of flue gas to 1/5th of that obtained in an open furnace. This high temperature gas is then subjected to usual steam Rankine cycle to drive a turbine and produce electricity. DSLA system integrates the hood-cooling system of the furnace. The latter can operate through evaporative cooling method mentioned earlier.

The energy content of furnace offgas, of a 30 MW ferrosilicon furnace has been estimated to be 9,500 Kwh per tonne of ferrosilicon produced, or 50 per cent of the total energy input (Eriksen, 1979). With 80% boiler efficiency, 7,600 Kwh of energy in the form of high pressure steam and about 2,280 Kwh of energy in the form of electricity can be recovered, with 30% efficiency of turbo-generator set. This means a recovery of 25% of the electrical energy input.

Production of ferrosilicon is a high temperature process, compared to ferromanganese, and ferrochrome. Consequently, recovery of waste heat in the forms of steam or electricity would be lower in cases of latter types of ferroalloys. Waste heat can be effectively used for preheating incoming charge, in case of ferrochrome manufacturing.

Ferrosilicon manufacturing is not amenable to charge preheating. A better way of conserving energy is, therefore, recovery in the form of electricity. The amount of electrical energy that could be potentially recovered from the ferrosilicon furnace only is more than 37 MW, by the year 2000, if all the present and future units are fitted with DSLA system and furnaces operate for 7000 hours per year. In India, M/s Indian Metals and Ferro Alloys are in contact with M/s Elkem a/s of Norway, for a scheme for energy recovery from their 24 MVA ferrosilicon and one of their newer furnaces(Elkem a/s). With 25% recovery of electricity input, ferroalloys industry, in general, offers a good scope for bottoming cycle cogeneration.

5.3 Benefit-cost of Bottoming-cycle Cogeneration

An existing ferroalloys making plant, which is actively considering recovery of 9.8 MVA of electrical power from one of its furnaces, requires Rs. 150 million of additional investment for retrofitting cogeneration system. Its annual savings estimated to be Rs. 66.24 million are due to electricity production from furnace offgas. With a discount rate of 2%, and an assumed working life of 20 years, the benefit-cost ratio works out to be nearly four, i.e., within the working life, nearly four times the initial investment would be returned in the form of savings from electricity production at zero fuel costs. Thus, in ferroalloys industry, cogeneration of electricity is a profitable proposition.

6.0 GLASS MAKING INDUSTRY

6.1 Status of Industry

There are at present 34 units engaged in the manufacture of glass bottles, tumblers etc., eight units in manufacturing sheet glass and few units in manufacturing items like vaccum flasks, laboratory wares, glass parts and fluorescent and GLS lamps etc. The total installed capacities for glass containers and sheet glass are 463,000 tonnes and 29.5 million square meters respectively(The Stock Exchange Official Directory, Vol.6, Bombay Stock Exchange).

6.2 Energy Consumption Pattern

The present study is based on energy audit of one glass container making unit, situated near Delhi(Tata Energy REsearch Institute). The factory was established in 1964, and has since been producing glass containers. The plant has three continuous glass making furnaces of regenerative type.

Energy is supplied to the plant in the form of petrofuels and electricity. Heat energy supply to the melting ends of all the furnaces is done by burning furnace oil. The refining ends of two furnaces are heated with light diesel oil. The feeders (the channels connecting refining ends of furnaces and forming machines) are heated with liquid petroleum gas and electricity. Electricity is used in the plant for purposes of heating some equipment, such as annealing lehrs, ACL ovens and also for running drives of such facilities as air compressors, blowers, fuel oil pumps, material handling equipment etc. Electricity is purchased from the State Electricity Board and to augment purchased electricity, the glass plant operates a battery of captive electricity generating units energised by high speed diesel oil.

The energy audit, amongst many other findings, revealed that

- The proportion of thermal (all petrofuels) energy to electrical energy (both generated and purchased forms of electricity) remained at 56:44 during the past five years.

- The single largest consumer of petrofuels as sources of thermal energy, were the melting ends of furnaces (74%), followed by forming process (7%) and refinings ends of the furnaces (3%). If, however, plant utilities are included, gensets became the second largest consumer (about 16%) of petrofuels.

- The largest consumers of electrical energy apparently were services like, plant illumination, ventilation, repair and maintenance, electroplating etc., which consumed about 30% of the total electrical energy consumption. Air compressors between themselves were the second biggest (about 26%) consumers of electricity. ACL ovens and annealing lehrs were the next biggest consumers of electricity (about 22% and 15% respectively).

- The energy intensity of white glass produced by one of the larger furnaces had been steady at 3.06 G-cal per tonne of glass produced. The corresponding recent figure of amber glass was 2.79 G-cal per tonne.

- For the melting ends of furnaces, the thermal energy associated with flue gases varied between 17 and 21%.

6.3 Bottoming-cycle Cogeneration Potential

The amount of energy associated with flue gas leaving the melting and regenerators of furnaces shows the potential of electricity generation from furnace waste gas. At full capacity of furnace operation, the total flue gas output from the three glass furnaces is estimated by stoichiometric calculations, to be 20,072 Kg. per hour at 390 deg.C.

Using the quantitative relationships between flue gas flow rates and net electric power generation and also between the former and installed equipment costs, (established through extensive plant level experiments at a glass factory in the U.S.), the net electric power generation and installed equipment costs were estimated for a bottoming-cycle cogeneration plant, using either steam Rankine cycle (SRC) or organic Rankine cycle (ORC).

The techno-economic analysis of the cogeneration scheme showed that

- The estimated installation costs of cogeneration system based on SRC and ORC that could handle the waste gas generated at melting ends of all the furnaces are Rs. 14.4 million and Rs. 11.2 million respectively.

- The corresponding yearly benefits (production of electricity at zero fuel costs) are Rs. 0.066 million and Rs. 0.092 million respectively.

- With an assumed operating life of 20 years for the cogeneration system, SRC is financially not viable. ORC might pay for itself in its operating life, but only at a very low discount rate of 5%.

The profitability picture changes much in favour of ORC, if one considers the 100% depreciation allowance permitted by the Union Government for incorporation of ORC. Inclusion of such depreciation allowance enhances cash inflow and the internal rate of return works out to be about 18 with an operating life of 20 years.

7.0 Impact of Bottoming Cycle Cogeneration on Industrial Scene

With the specific examples of three types of manufacturing industry, we showed the extent to which bottoming cycle cogeneration can be applied in industry. It can be said that this type of cogeneration can make use of waste heat from three sources viz.

- Waste heat (comprising mostly of sensible heat of products of combustion) of direct fossil fuel fired combustion process(Chiogioji, 1979). Typical examples are flue gases from process furnaces, kilns, ovens etc. In more modern and large scale units, these furnaces are equipped with regenerators and recuperators, e.g. coke ovens, open hearth furnaces, or glass tank furnaces, soaking pits of steel rolling mills or arrangements are provided to preheat incoming raw materials by direct or indirect heat transfers, e.g. suspended preheaters of kilns employing dry process of cement manufacturing. In such cases, the temperature of products of combustion at or near the chimney becomes too low (less than 400 deg.C)for economic implementation of cogeneration through steam Rankine cycle. This has been examined in the previous section with an example of a glass unit.

It is possible to estimate, roughly, the quantum of electrical energy that can be produced from the waste heat generated from this category of source.

The total thermal energy input during 1979 through direct fossil fuel fired combustion process, has been estimated(Tata Energy Research Institute) and are given in Table 5.

Table 5: Thermal Energy Input through Cost and Petrofuels to Several Indian Industries during 1979.

(in 10^{12} calories)

Through Coal		Through Petrofuels	
Type of Industry	Heat Input	Type of Industry	Heat Input
Boiler furnaces of electrical utilities	150,150	Furnace of Chemical and allied industries	8,248
Iron and Steel plants and Coke Ovens	43,082	Iron and Steel	4,383
Cement kilns	19,350	Textile mill boilers	4,373
Textile mill boilers	9,950	Boiler furnaces for electrical utilities	2,583
Paper mill boilers	7,700	Furnaces of ceramics and glass industry	1,882
Brick kilns	2,700	Cement kilns	1,566
Jute mill boilers	700	Alliminium melting	1,241
		Unspecified industry	669
		Sugar mill boilers	417
Total	233,632	Total	25,362

Note: Compiled by the author from Tata Energy Research Insitute.

We see that total heat input to a wide ranging industry, 12 through fossil fuel was 258,994 x 19 calories, during 1979.

It is known that the quantity of heat energy that escapes through the chimney depends mostly upon the temperature (and also oxygen content) of the flue gas. For a temperature of waste gas around 400 deg.C, such loss amounts to about 20 % (Tata Energy Research Institute). Thus, the amount of energy lost through flue gas in 1979 is estimated to be 51,799 x 1012 calories. On the assumption that the overall thermal efficiency of a Rankine cycle is 30%, i.e. 2.853 G-cal of thermal energy input is needed to produce 1 Mw-hr of electrical energy, the quantity of electrical energy that can be produced from the estimated thermal energy associated with flue gas is more than 18 million hr per year or is equivalent to about 2,600 of electrical power with 7000 hours of operation per year.

Because of smaller scale of operation and high dispersion of industries in India, a small fraction of electrical power is recoverable in practice.

- furnace offgas. Typical examples are offgas from basic oxygen furnaces for steel making and those from ferroalloys making furnaces. Both types have been discussed in detail in earlier sections. Furnace offgas has substantial calorific value (about 2000 K-cal per nM3) in addition to sensible heat. It has been observed that, even in large scale organisations like integrated iron and steel units having BOF, there has so far been no attempt to recover this offgas either for cogeneration or for any other purposes.

- new sources. Typical example is dry quenching of coke. Strictly speaking this belongs to the first category, but this type of new source must be treated separately because of the nature of unconventional technology involved.

The candidate industries, which can implement bottoming system cogeneration, by virtue of being one or other kind of three types of source of waste heat, are quite varied in India by their scale of operation, vintage, extent of technological and managerial sophistication etc. Energy management in general and waste heat recovery in particular at enterprise level has of late made some impact. Some units, which had no recovery facilities in their high temperature processing units, have installed recuperators(National Productivity Council, New Delhi), and started saving fuel. However, there has been no attempt at cogeneration, because these units do not use a substantial quantity of electricity.

This is a typical example of cogeneration competing with other methods of waste heat recovery.

Even units suited for bottoming cycle cogeneration e.g., ferroalloys, calcium carbide making etc. cannot immediately go for it because of their scale of operation, and consequent production of furnace offgas. However, units having large number of small furnaces can think of constructing common gas collecting manifolds, cleaning and storage systems before steam boilers. Similarly, use of gas turbine as replacement of waste heat boiler and condensing steam turbine, can also be actively considered for high efficiency use of waste heat. For such electrothermal industries, which consume large quantities of electricity and release rich furnace offgas, bottoming cycle cogeneration has been shown to be a profitable proposition.

A barrier to implementation of bottoming cycle cogeneration is the lack of suitable equipment and accessories. Though Bharat Heavy Electricals Ltd., have developed waste heat boilers of different duties and are ready to market them, there is a shortage of smaller sized (say, less than 1 MW,) steam turbines, and gas turbines and their accessories. Similarly, there is no effort to develop and commercialize organic Rankine cycle components, ideally suited for energy recovery at low temperature waste heat.

Finally, many units would opt for cogeneration (particularly topping cycle where first electricity is produced, then low pressure steam as a coproduct for use in the process, e.g. pulp and paper, chemicals) if the price of electricity as supplied by utilities like State Electricity Boards, is raised substantially. Till such time, the industrial consumer of electricity would purchase electricity instead of producing the requirement (whole or part) through cogeneration.

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